

Impact of the Proposed Moifjellet Wind Farm on the Hægebostad Weather Radar

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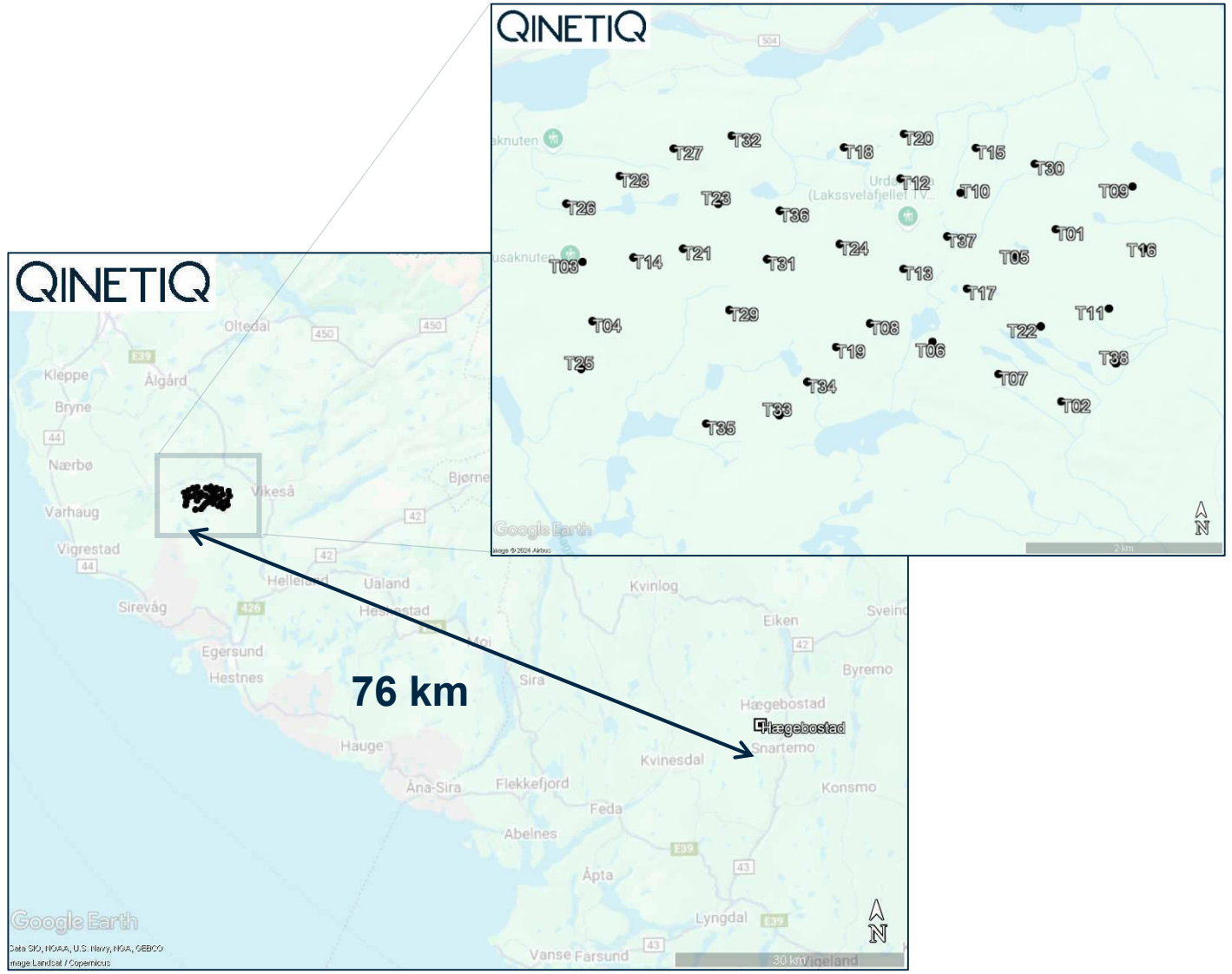
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Introduction

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Background

- Statkraft intends to develop the Moifjellet wind farm: 38 turbines with a maximum height of 200m
- The Moifjellet wind farm project definition is taken from [1]
- The locations and dimensions of other wind farms in the vicinity are also taken from [1]
- The Norwegian Meteorological Institute (NMI) are concerned that the project will have a negative impact on the operation of the Hægebostad weather radar [2].



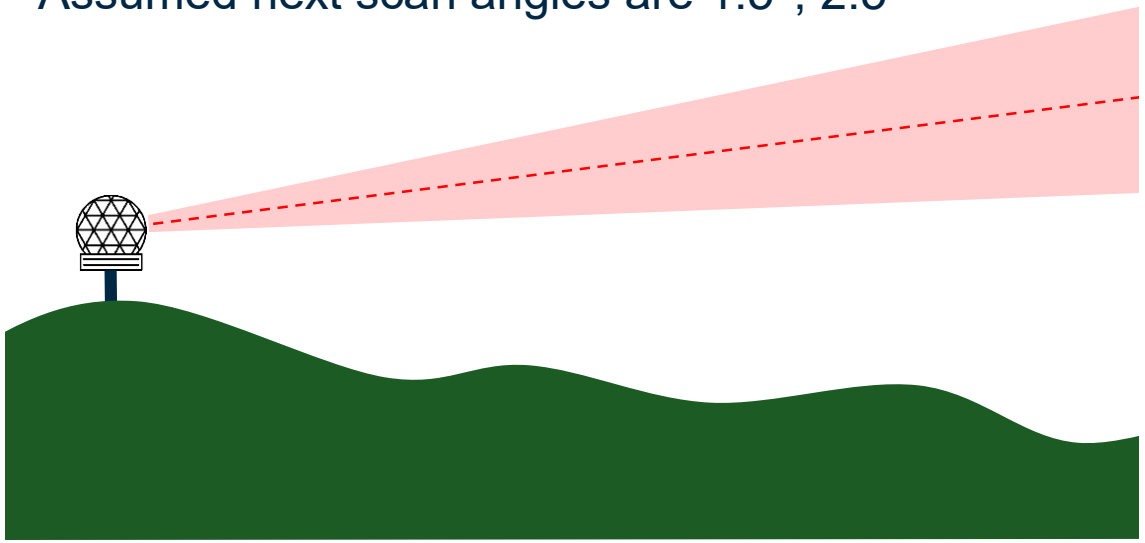
[1] Savage, V. (QinetiQ), “Impact of the Proposed Moifjellet Wind Farm on the Skykula Military Radar”, September 2024, QinetiQ/23/02032/2
[2] Magnus, L. M. (Statkraft), “Updated radar assessment for Moifjellet wind farm”, email to Savage, V. (QinetiQ), 25 JUL 2024

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Hægebostad Weather Radar

- Radar location WGS84
  58.360145°N 7.164810°E [1]
- Antenna height = 631m above sea level
- Frequency = 5.64 GHz (C-band)
- Beam width = 1.0°
- Lowest scan elevation angle = 0.5°
- Assumed next scan angles are 1.5°, 2.5°

The radar uses a ‘pencil’ beam, narrow in horizontal and vertical angle. The radar makes one full 360° horizontal rotation at the lowest scan angle. It then makes rotations at increasing elevation angles to build-up a 3D radar picture of precipitation.

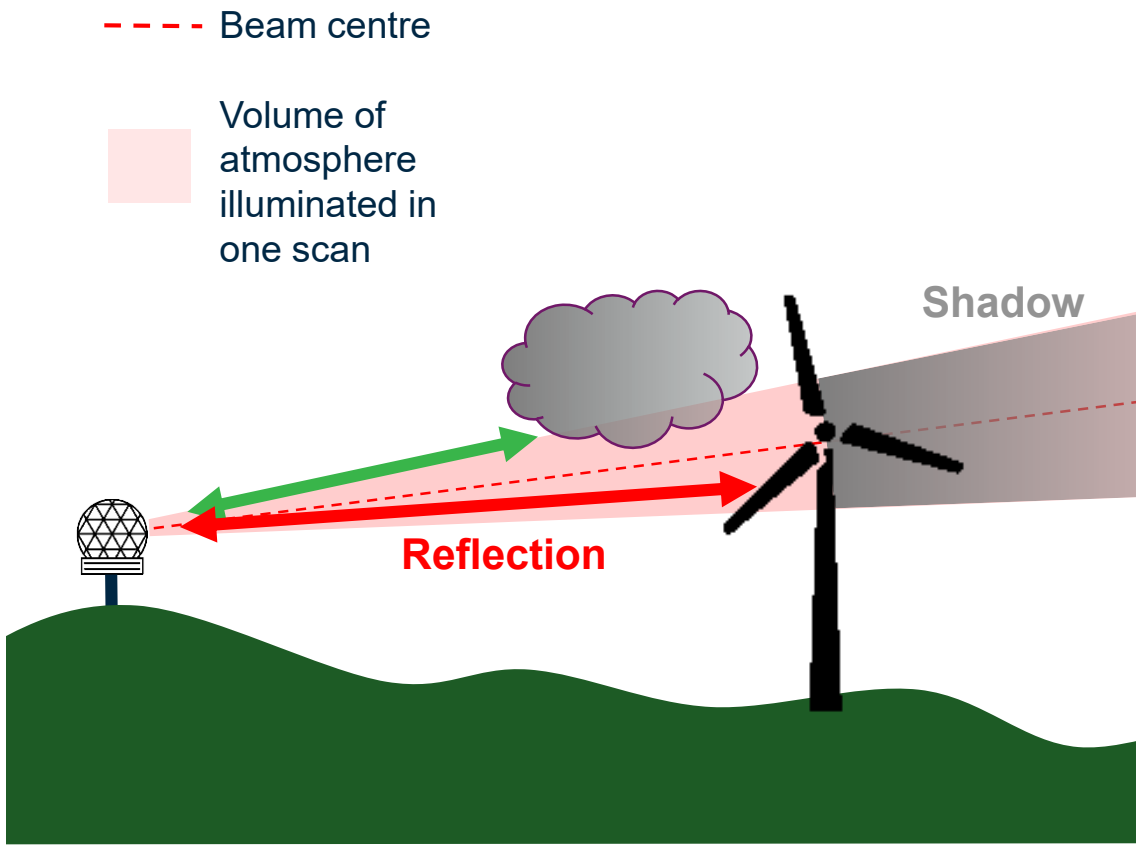


[1] Magnus, L. M. (Statkraft), “Updated radar assessment for Moifjellet wind farm”, email to Savage, V. (QinetiQ), 25 JUL 2024

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Wind Turbine Impacts

- **Green** = intended operation = reflections from precipitation (rain, hail, mist etc.)
- Wind turbines have two main impacts
  - **Red** = reflection from turbine = fictitious increase in precipitation estimate
  - **Grey** = shadow (signal blockage) behind the turbine = decrease in precipitation estimate

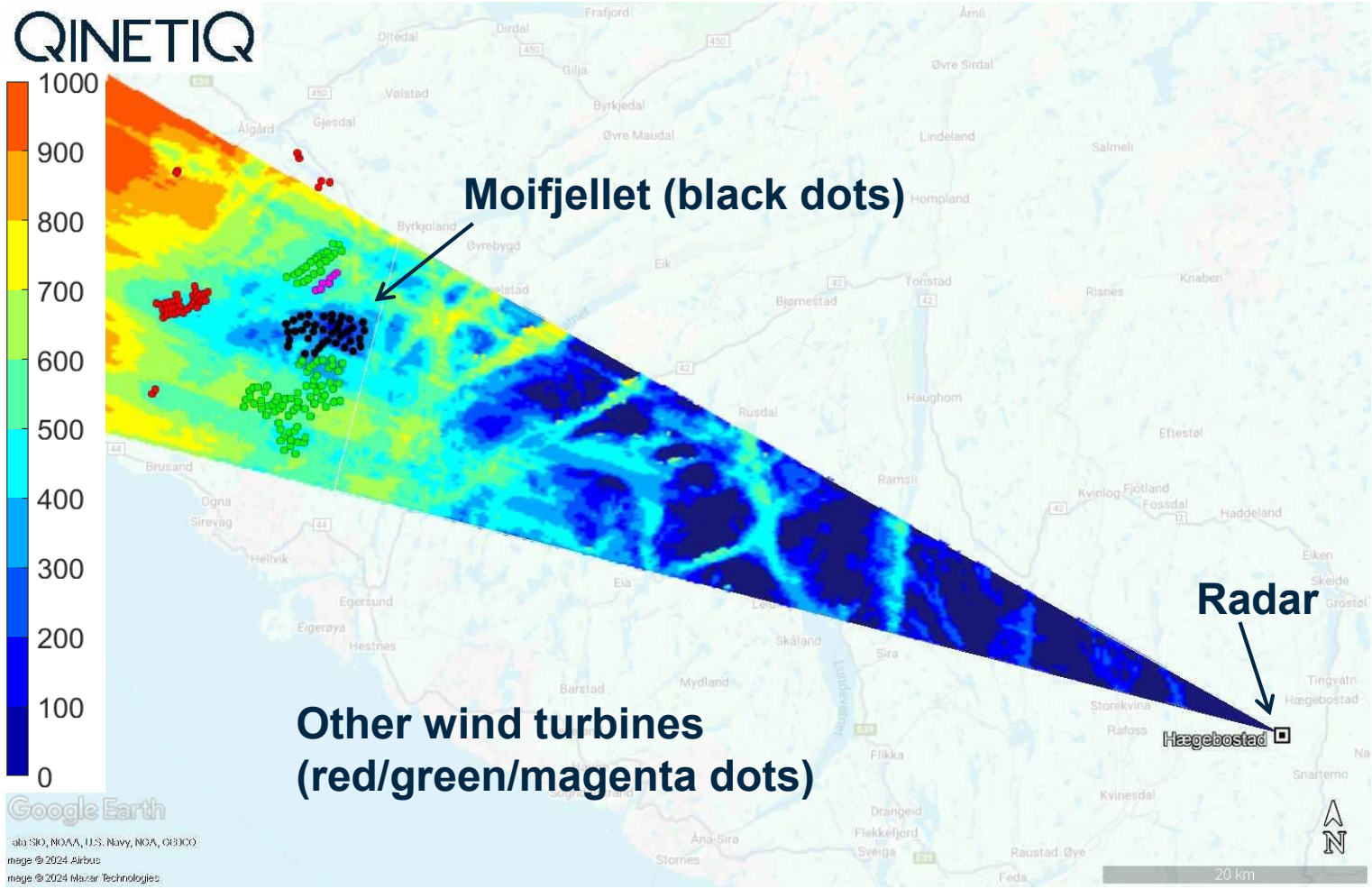


Wind farm visibility

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Turbine Visibility (1/4)

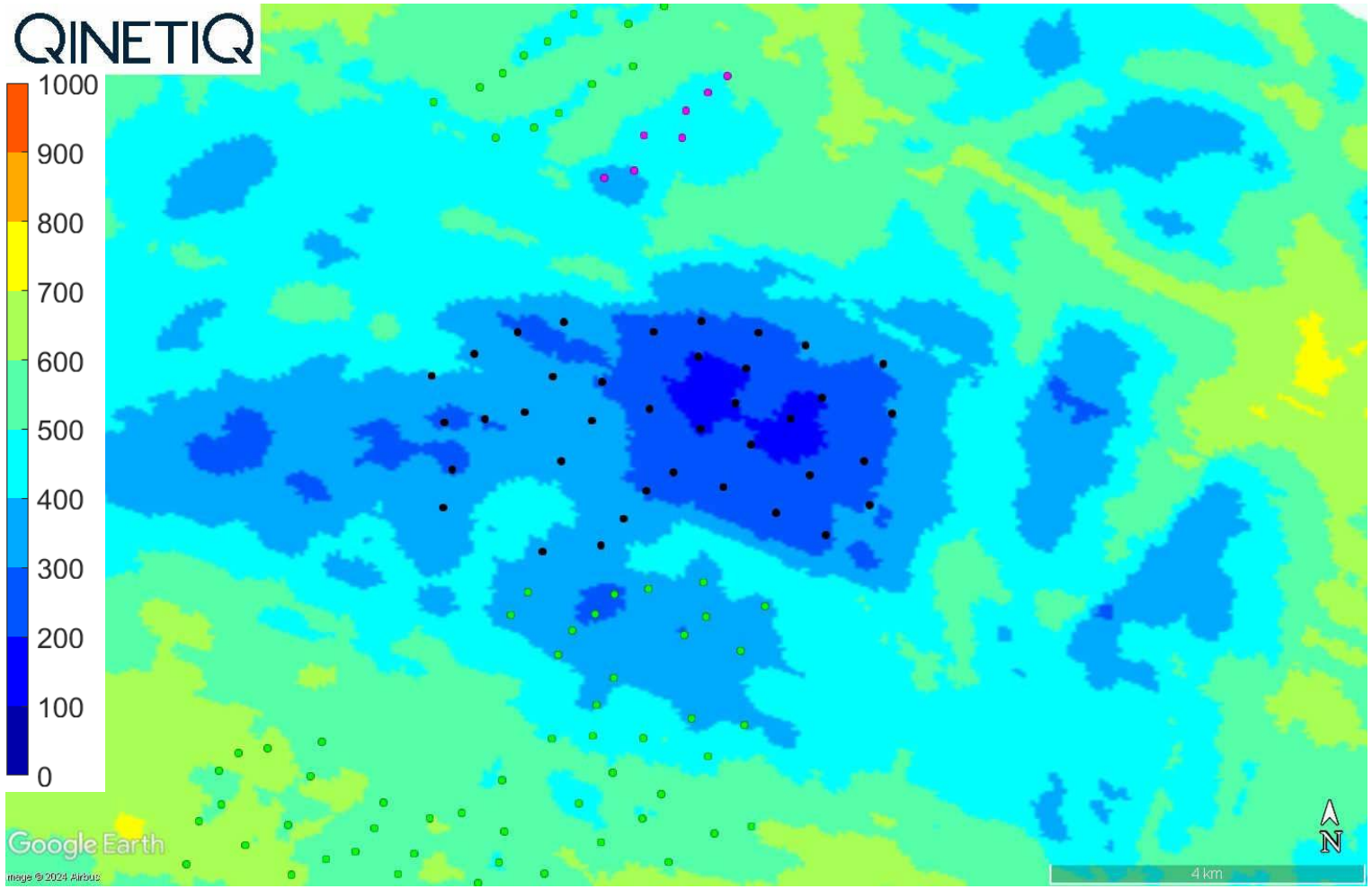
- Colour shows height to radar line of sight (LOS) from the Hægebostad weather radar
- For example, yellow areas indicate where an object 700m or smaller is not in LoS (not directly visible) from the Hægebostad weather radar



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Turbine Visibility (2/4)

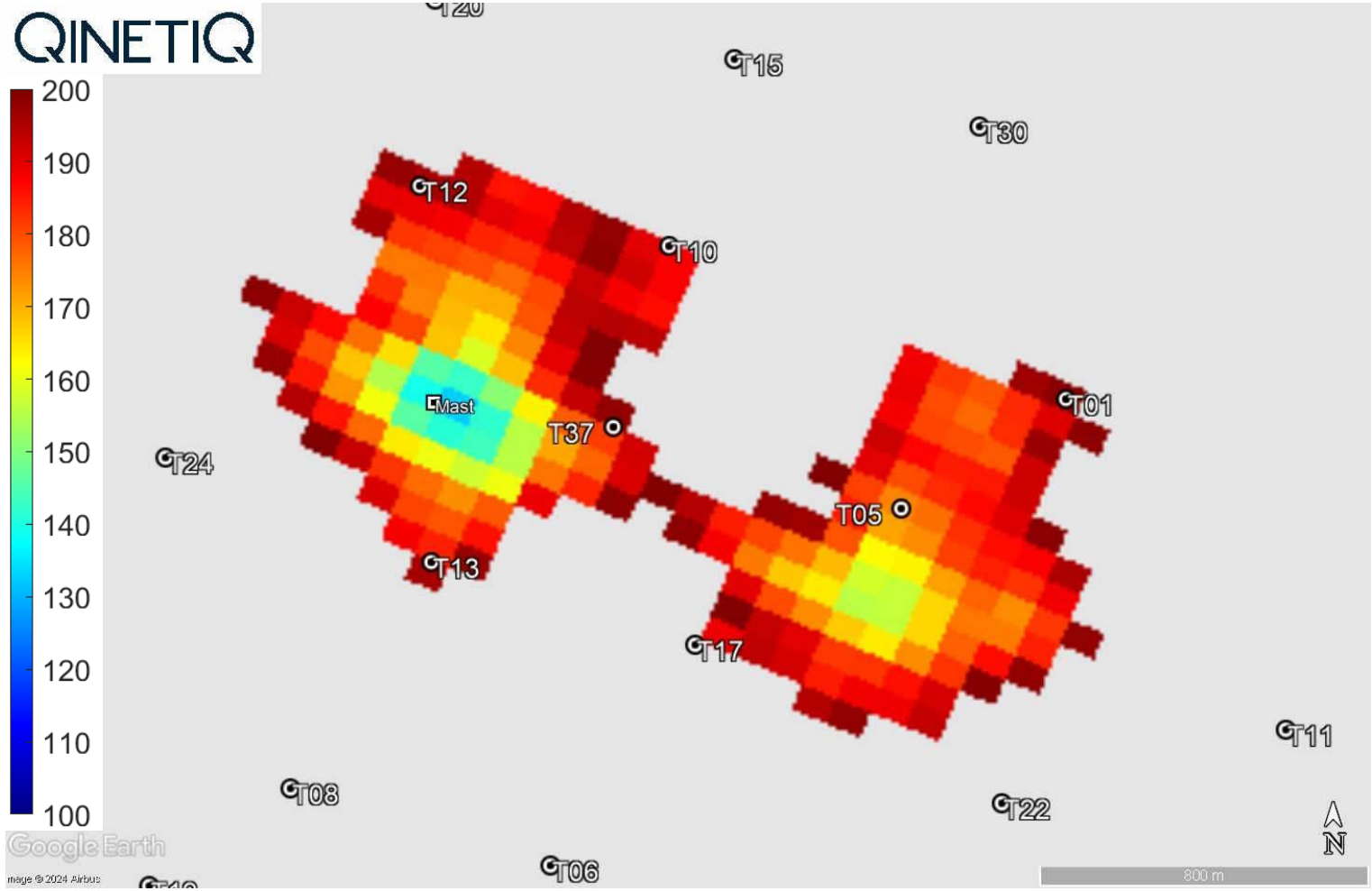
- The radar LoS in the vicinity of the proposed Moifjellet wind farm varies from 174m to 391m
- All other wind farms are out of radar LoS from the weather radar



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Turbine Visibility (3/4)

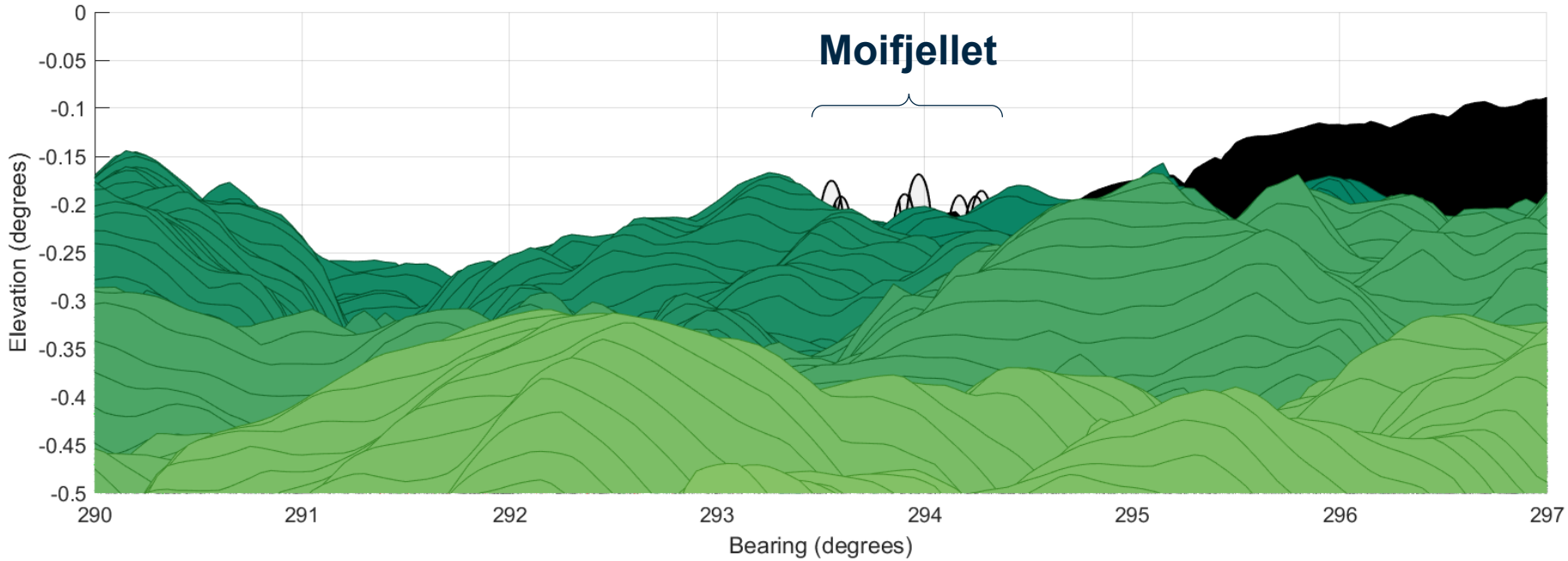
- Radar LOS detail – only turbines T01, T05, T10, T12, T13, T17 and T37 are directly visible from the radar (HTLOS ≤ 200m)



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Turbine Visibility (4/4)

- Radar view. Visible turbines:
  - Azimuth (horizontal) sector 0.9° [293.4°N to 294.3°N]
  - Elevation (vertical) sector 0.06° [-0.23° to -0.17°]



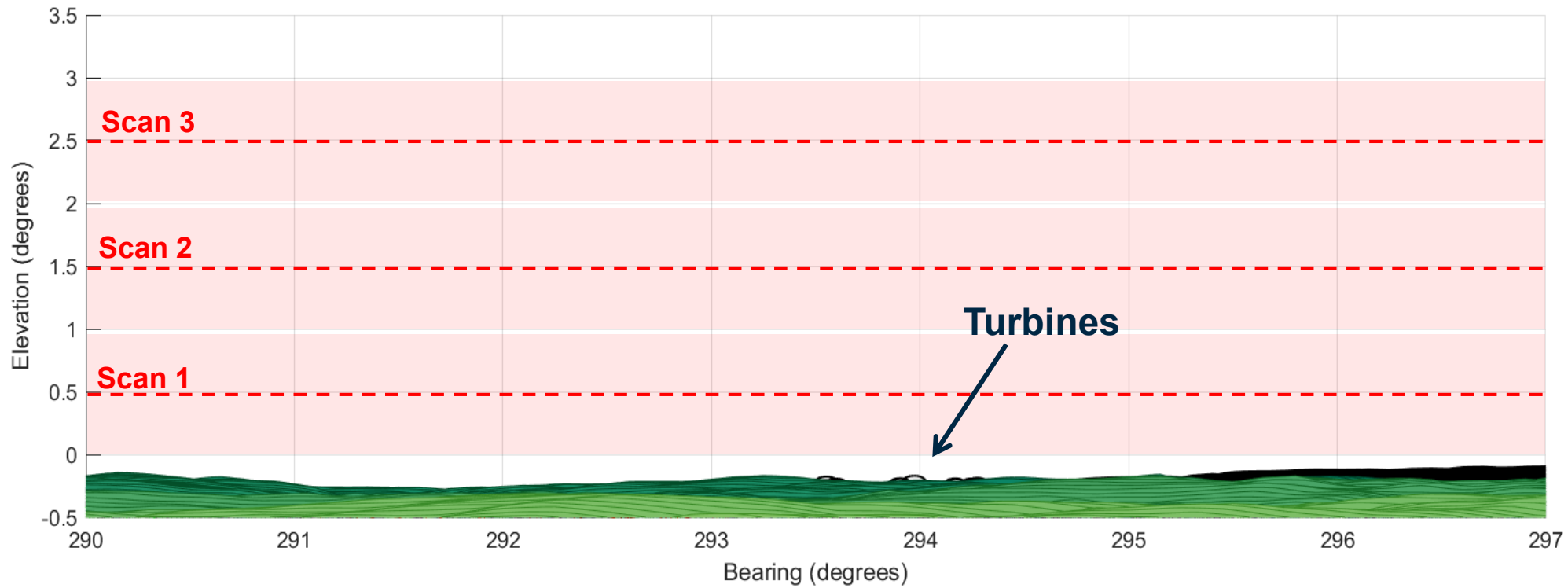
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Shadowing

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Scan angles

- Visible turbines are entirely underneath the lowest scan angle
- Impact judged to be negligible



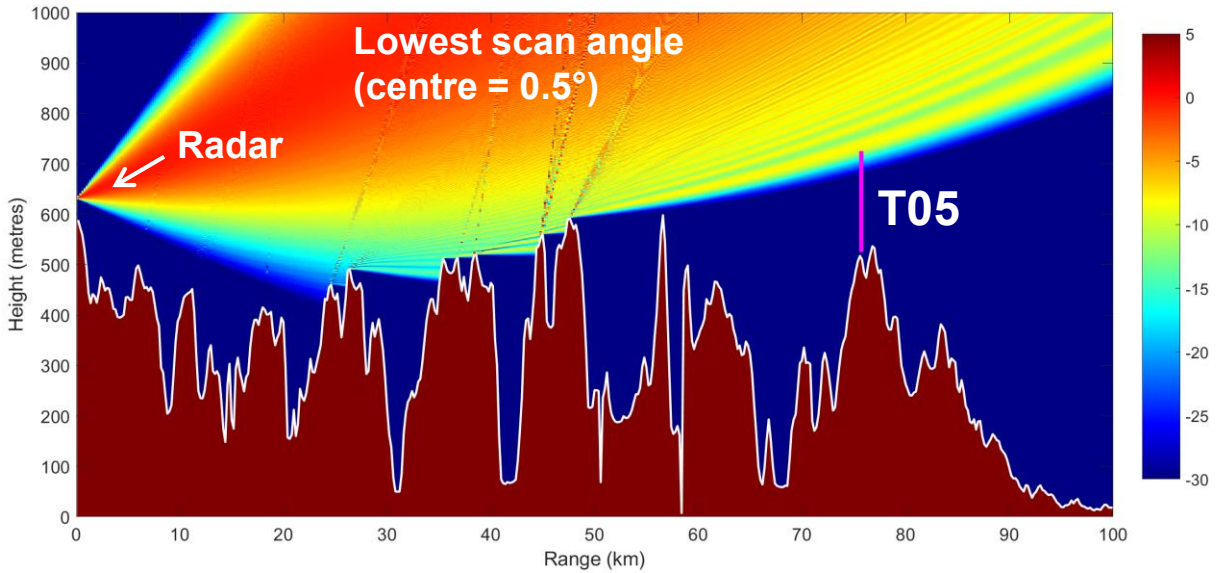
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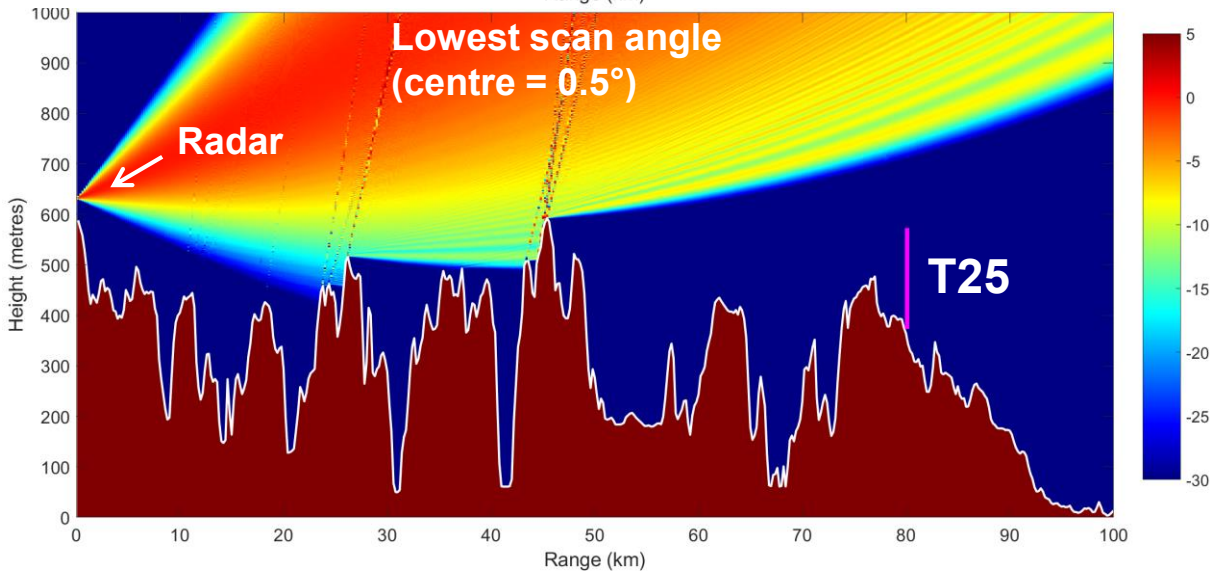
Reflections

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Signal propagation

- Representative* radar signal propagation at lowest scan angle shown to right, for T05 (most visible turbine) and T25 (out of LOS on similar bearing)
- Colour indicates 2-way power signal strength relative to free-space (no terrain)





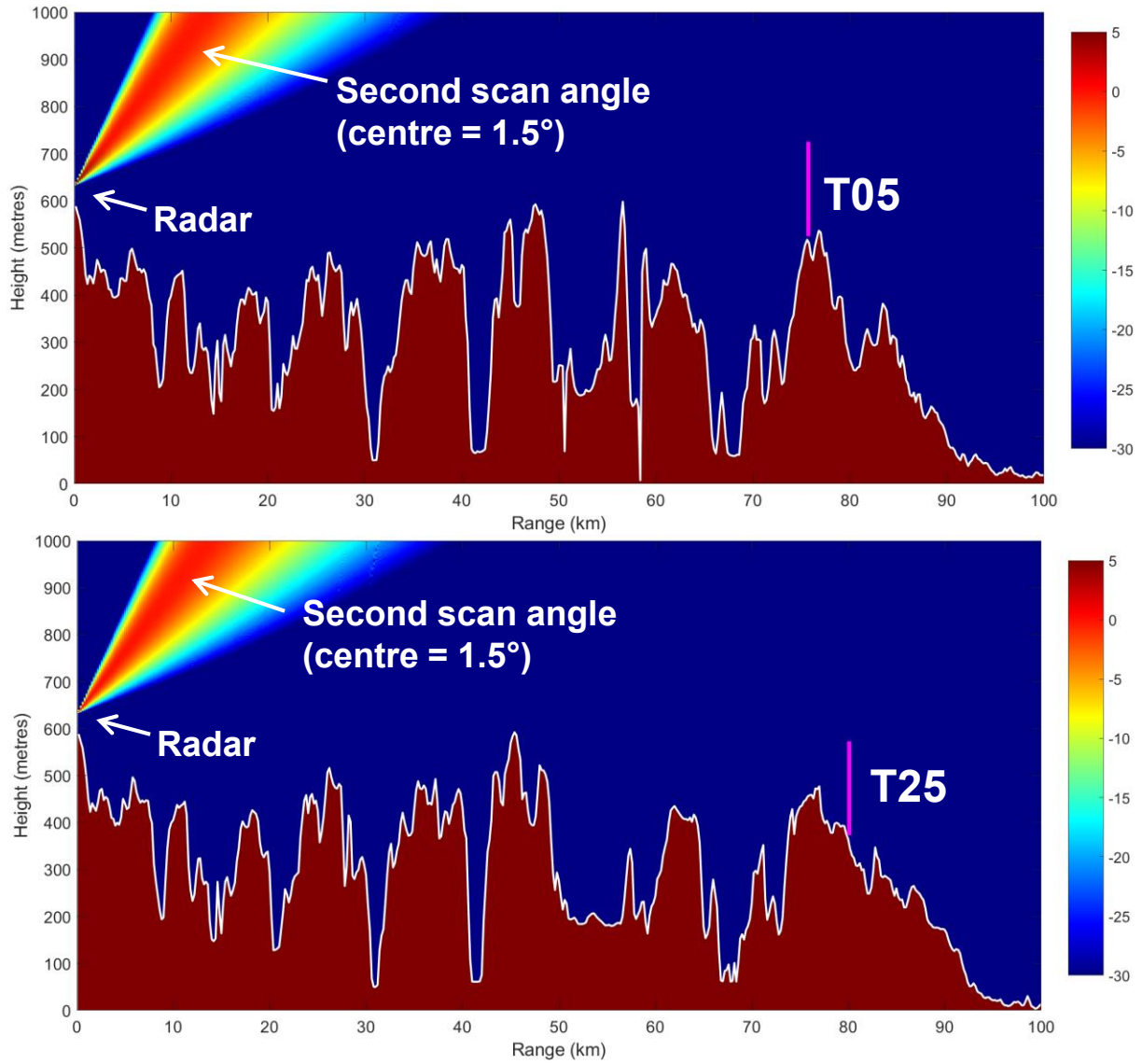
This slide shows some radar signal reaches the turbines in radar LoS. Compare with Slide 12 which uses a simpler “3dB half-width” antenna beam model. The red/orange colour in this slide corresponds to the pink polygon “Scan 1” in Slide 12.

Radar signals appear to bend “up” in the figures. This is a result of Earth curvature and atmospheric refraction

* the beam pattern has not been provided for this assessment. A typical weather radar pencil beam with 1° beam width is used in this example

Signal propagation

- Analysis repeated with second scan angle
- Unlikely to see significant reflections at this scan angle (or higher scan angles)



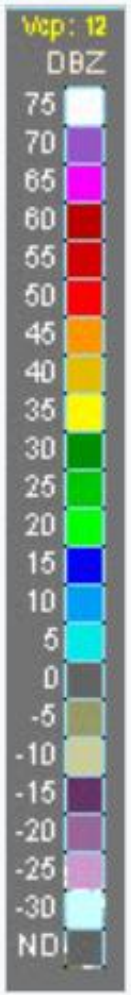
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Reflection strength

- Reflectivity (dBZ) from turbines estimated based on scaling strength of reflections from measurements
- Estimate for Moifjellet for 7x turbines in radar LoS (see Slide 9)
    - 53 dBZ (maximum infrequent blade flash) ≈ “heavy rain”
    - 33 dBZ (average blade reflection) ≈ “moderate rain”

  Clutter impacts will appear at the location of the turbines (see next slide)

- Turbines out of LOS: reflections possible due to diffraction over the terrain, but strength will be significantly reduced



Reflectivity in dBZ and Rainrate

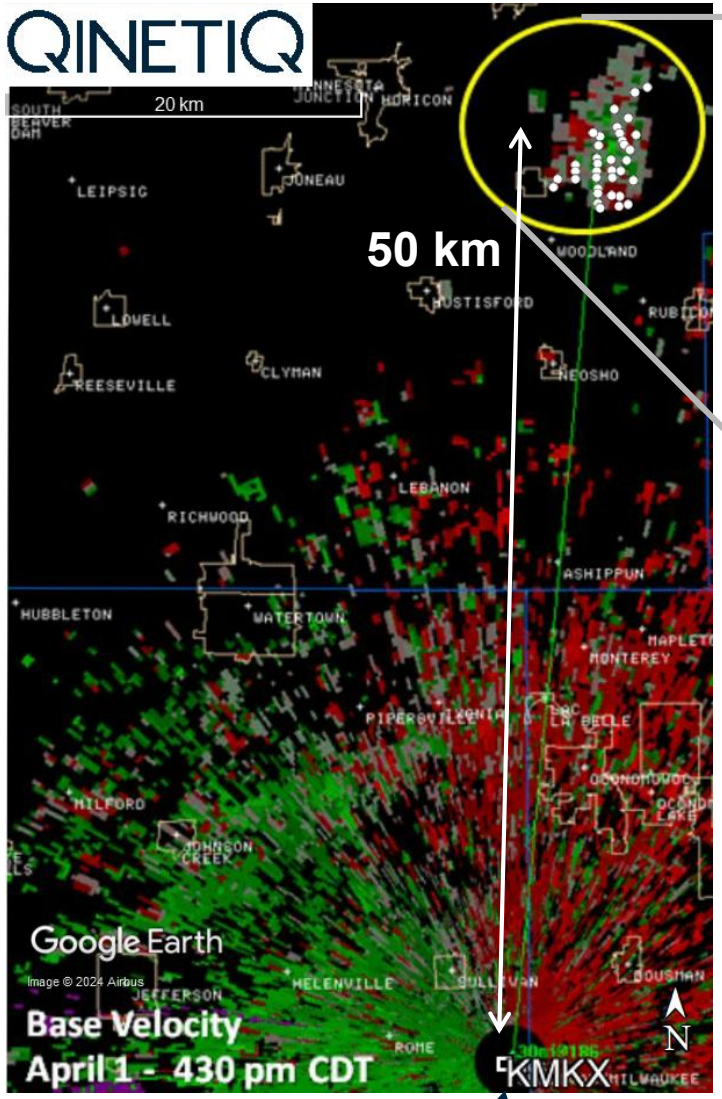
L_Z (dBZ)	*R* (mm/h)	*R* (in/h)	Intensity
5	0.07	< 0.01	Trace accumulation or mist
10	0.15	< 0.01	Trace accumulation or mist
15	0.3	0.01	Trace accumulation
20	0.6	0.02	Light rain
25	1.3	0.05	Light rain
30	2.7	0.10	Light to moderate rain
35	5.6	0.22	Moderate rain
40	11.53	0.45	Moderate to heavy rain
45	23.7	0.92	Heavy rain
50	48.6	1.90	Heavy rain, small hail possible
55	100	4	Very heavy rain, hail possible.
60	205	8	Very heavy rain, hail likely.
65	421	16.6	Very heavy rain, hail very likely, large hail possible.

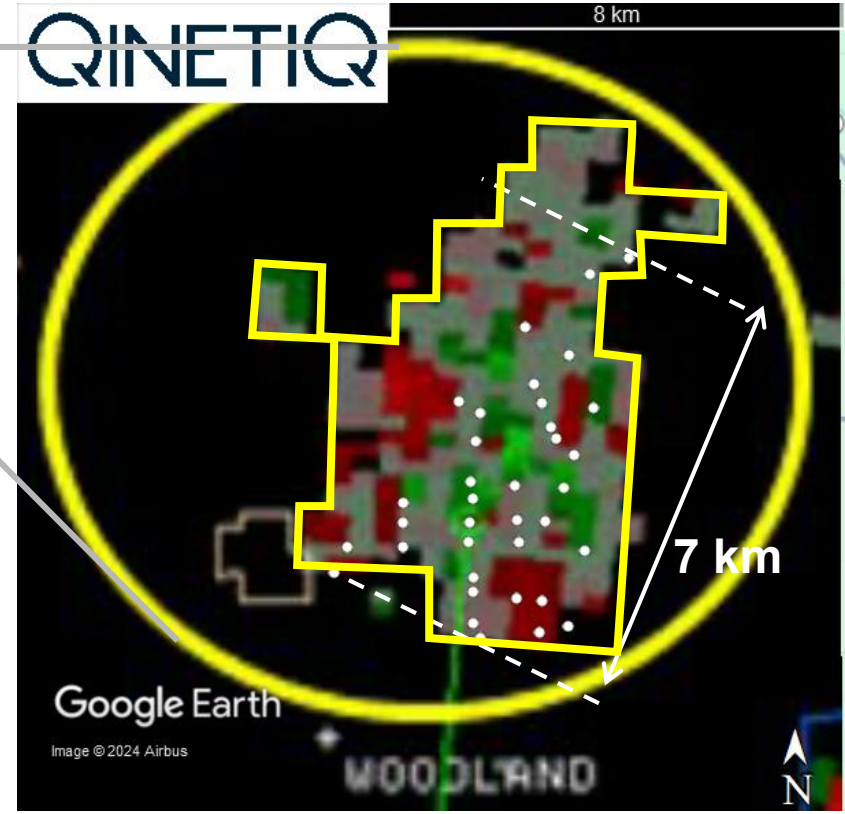
https://en.wikipedia.org/wiki/DBZ_(meteorology)

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Reflection strength

- Example of wind farm clutter from United States National Weather Service (NWS)
- Clutter (yellow polygon) local to wind turbines (white dots); extending a few km from the turbine locations





Radar

Data from
https://www.weather.gov/mkx/windfarm

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Acceptability

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Acceptability

- What level of interference is acceptable?
- The acceptance criteria are not known
- For comparison: the impacts would be acceptable in e.g. France* and the UK (safeguarding distances = 20km for a C-band radar).

*

	Distance minimale d'éloignement en kilomètres
Radar de bande de fréquence C	20
Radar de bande de fréquence S	30
Radar de bande de fréquence X	10

https://www.legifrance.gouv.fr/loda/id/JORFTEXT000024507365

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Summary

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Summary

- Statkraft intend to develop the Moifjellet wind farm approximately 76km north west from the Hægebostad weather radar
- The NMI are concerned that the project will have a negative impact on the operation of the radar
- A top level estimate of the impact concludes
  - Visibility (Slides 6 to 10): Seven* turbines in radar LOS.
  - Shadowing (Slide 11 to 12): No significant impact. Turbines are entirely below the strongest part of the lowest elevation scan angle
  - Clutter (Slide 13 to 17). Reflections from the turbines are possible, likely to be within a few km from the turbines. Reflection strength estimates in table to right
- Acceptability (Slide 19)
  - NMI acceptance criteria not known
  - The impacts would be acceptable in e.g. France / UK …
  - … but it is for NMI to determine the acceptable interference levels for their radar

Impact	Turbines in direct radar LOS*	Remaining turbines
Maximum (infrequent) reflection from rotating blade flash	53 dBZ ≈ “heavy rain”	Reflections possible due to diffraction over terrain but less than from turbines in LOS.
Average reflection	33 dBZ ≈ “moderate rain”	

*T01, T05, T10, T12, T13, T17 and T37

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